IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Appl. No. : 10/674,997 Confirmation No. 5257
Applicant : Janakiraman Vaidyanathan et al.
Filed : September 30, 2003
TC/A.U. : 1725
Examiner : Geoffrey S. Evans
Docket No. : EH-10885(03-368)
Customer No. : 52237

DECLARATION UNDER 37 C.F.R. 1.131

We, Janakiraman Vaidyanathan and Kenneth Pietrzak, declare that they are the inventors who, on September 30, 2003, filed the above-identified application; that they completed their invention having made a written description thereof with pictures and disclosed the same to others, in this country prior to June 4, 2003, the filing date of the application from which U.S. Patent No. 6,723,951 matured; that prior to June 4, 2003, they prepared a written description and drawing, a copy of which is attached hereto; that they do not know and do not believe that the invention has been in public use or on sale in this country, or patented or described in a printed publication in this or any foreign country for more than one year prior to their application, and they have never abandoned his invention.

The undersigned declare further that all statements made herein of their own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Dated: 3/22/05 — J Vaidyanathan

Janakiraman Vaidyanathan

Dated: ____________________ ____________________

Kenneth Pietrzak

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Appl. No.	: 10/674,997	Confirmation No. 5257
Applicant	: Janakiraman Vaidyanathan et al.	
Filed	: September 30, 2003	
TC/A.U.	: 1725	
Examiner	: Geoffrey S. Evans	
Docket No.	: EH-10885(03-368)	
Customer No.	: 52237	

DECLARATION UNDER 37 C.F.R. 1.131

We, Janakiraman Vaidyanathan and Kenneth Pietrzak, declare that they are the inventors who, on September 30, 2003, filed the above-identified application; that they completed their invention having made a written description thereof with pictures and disclosed the same to others, in this country prior to June 4, 2003, the filing date of the application from which U.S. Patent No. 6,723,951 matured; that prior to June 4, 2003, they prepared a written description and drawing, a copy of which is attached hereto; that they do not know and do not believe that the invention has been in public use or on sale in this country, or patented or described in a printed publication in this or any foreign country for more than one year prior to their application, and they have never abandoned his invention.

The undersigned declare further that all statements made herein of their own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Dated: ______________________

____
Janakiraman Vaidyanathan

Dated: 3-22-05

____
Kenneth Pietrzak

INVENTION DISCLOSURE

Pratt & Whitney
A United Technologies Company

Title Stereovision guided laser drilling system

Patent Project No. EH-10885

Introduction

In the turbine blades/vanes manufacturing process, the parts are first precision-cast and then the cooling holes are installed either by laser drilling or by EDM. A method that casts the cooling holes at the time of casting the part, offers the advantage of process simplification with enhanced quality and precision. Also very complex cooling hole schemes (shaped non-cylindrical holes with complex diffuser and metering section geometry) can be cast in by this process that are difficult to directly laser drill or EDM. But even a high-precision casting process cannot fully cast the complete hole geometry due to the limitations of the casting process (cold shut, core mismatch, slag formation etc). These limitations result in partially cast holes - with most hole geometry complete except the bottom portion. If this problem can be addressed, one of the major problems in cast-in shaped holes will be solved.

In this disclosure, a novel approach is outlined for locating and finish drilling such partially cast-in cooling holes by a *stereovision guided laser drilling* process. The vision-guided system mounts right on the laser drilling machine and locates the position of each hole and guides the laser drill to the actual position of each cooling hole to fire the laser pulses to finish off the partially drilled holes.

This method offers the unique advantage of being adaptable right on the laser-drilling machine. A CATSCAN system can give 3-D inside and outside profiles but takes an inordinately long time to scan for the precision needed and also needs a separate radiation chamber. The evolving QMP (Quartz Micro Probing) system can locate the holes precisely but the rough locations must be known before hand. Also QMP takes a long time and cannot be mounted on the laser machine bed. 3D machine vision alternatives including structured light techniques proved difficult due to the depth or shallow angle the cooling holes. The proposed system is unique and solves the shortcomings of each of the above methods. It has a small footprint and mounts right on the laser drill. It is precise and quick and capable of covering wide areas.

Stereovision system development

A single Black & White CCD Video Camera with the desired pixel resolution and a PC-based PCI frame grabber form the core of the stereovision system. The vision system hardware was mounted on the laser machine slides, parallel to the laser axis and offset by a few inches (Fig. 1). A Windows NT machine vision program, developed using Microsoft Visual C++ handled all the software tasks. Components of this program included the camera calibration software, the image processing software, the stereovision algorithm, and the laser/camera alignment software. The program used a standard Windows interface complete with a toolbar for selecting various operations.

The camera calibration routine calibrated the camera for the perspective transformation, scaling factors, radial lens distortion, and the transformation from the camera coordinate system to the machine coordinate system. Camera calibration required the use of a calibration target that

Explained to and understood by:		Inventor(s):	
1. Brice Cassenti N.	1/6/03	Janakiraman VAIDYANATHAN	1/6/03
2. Wayde Schmidt R.	1/6/03	Kenneth PIETRZAK	
		LeRoy PUFFER	
Signatures	Date	Signatures	Date

included a backlit glass plate containing a grid of black squares. A 3D-to-2D mapping is generated using pairs of known world coordinates and measured camera coordinates for each corner of each square. The stereovision algorithm combined the camera coordinates for a feature from each image to generate a 3D coordinate in the machine's coordinate system. The image processing software processed each digitized image to locate the camera coordinates of each feature. The image processing software scanned the image with a set of various sized rectangular models using a normalized correlation approach. A good match indicated that the rectangular section at the bottom of the hole was located.

x, y of each image

Switch to holes

Binocular stereovision is the process by which three-dimensional structure is recovered from a pair of images of a scene taken from slightly different viewpoints. The difference in positions causes relative displacements or disparities that enable the depth to be calculated by triangulation. One of the major problems in stereovision is matching features in the two images. By focusing on one hole at a time and working in a known orientation, feature matching was uniquely solved in this application. Normally two cameras provide the pair of images required for stereovision in a similar fashion to human vision. In this case however by moving the blade to two different positions, just one single camera was used to obtain the pair of images. This reduced the footprint of the system and eliminated the need for the second camera.

correct to move part.

In the case where there was more than one hole in the image, the software selected the one that was closest to the nominal location. Using the stereovision algorithm, the camera coordinates from each corner of the rectangle were converted to machine coordinates. These corner locations were then used to generate a drilling location based on blueprint dimensions. The laser / camera alignment software was used to determine the physical offset between the camera and laser and to identify the nominal drilling location to the image processing software.

tube appears rectangular

retrieved and Stereo

Vision system setup

computer numerical control

A five-axis laser was used for the drilling in which the laser head (1) was stationary and the part (2) was moved under CNC control. The part could be translated in the three principal axis directions and the two rotary tables (3) carrying the part provided the three rotational degrees of freedom. The specially fabricated fixture (4) mounted on the machine table, provided the reference for mounting either the calibration block or the fixture carrying the blade. The Calibration block had a tiny pinhole that was used by the laser drill for providing the alignment of the laser axis. The same was used by the vision system (5) to align the vision system axis and for offset calculations between the laser and the vision system axis. The calibration block was designed to carry a calibration target (6) or square grid block. The optical system consisting of the light source (7), the collimator and the digital camera (8) was designed for easy assembly and the whole system was mounted around the cooling Copper tubes using standard V-block with clamps (9) that used the tube diameter as reference (Fig. 1 and 2).

sets offset between laser and vision system

The optical unit was mounted onto the laser head. The laser was aligned using the calibration block. The laser beam was positioned such that it passed through the center of the 0.001" diameter alignment hole. The machine home position was then reset to this location. Next the camera calibration target was mounted to the calibration block and the camera was calibrated by

Explained to and understood by:		Inventor(s):	
1. Brice Cassenti N. Brice N. Cassenti	1/6/03	Janakiraman VAIDYANATHAN [signature]	1/6/03
2. Wayde Schmidt R. [signature]	1/6/03	Kenneth PIETRZAK	
		LeRoy PUFFER	
Signatures	Date	Signatures	Date

moving the z-axis incrementally to several positions and processing the resulting square pattern image at each position. Next the machine position was adjusted so that the camera was focused on the front of the laser alignment hole and so that the imaged hole was at the nominal position in the image. The offset ~~between the~~ camera and laser home positions was then recorded from the machine axes values. The hole image was then processed to determine the 2D camera coordinates of the hole. The camera was then displaced by 0.1 in. to obtain the 2D camera coordinates from the Virtual Camera. The stereovision algorithm was then applied to obtain the hole position in machine coordinates using the parameters from the camera calibration. This position was stored by the vision system. [illegible] by laser

Operation

The nominal laser-drilling program was used to initially position each hole in front of the camera by adding the pre-calibrated offset between the camera and laser to each nominal hole drilling location. Using the stereovision technique, the vision system then computed the machine coordinates for each corner of the target hole. The drilling coordinates were then computed using these results. According to the blueprint, this location was the center of the corner hole radius tangent to one of the corners of the shaped diffuser hole. ~~The nominal machine coordinates obtained during the alignment step were then subtracted from this new position to yield the error offset~~. Once all the holes were located by the vision system, the program was modified by subtracting the error offset for each hole from each programmed laser drilling location. The laser then drilled each hole by firing the required amount ~~of pulses~~ using the modified program.

before imaging hole

based on imaging SH

I offset target

Fig. 3 shows an image of four of the holes in row PG. In this case hole PGC (second from the bottom) was the hole being located by the vision system. Fig. 4 shows the results of the hole drilling of all the PG row holes at this same vantage point. The dark disk shaped regions is the metering holes as drilled by the laser. The holes were drilled in the correct location despite the error in the position of the cast diffuser holes.

Explained to and understood by:		Inventor(s):	
1. Brice Cassenti N. [signature]	1/6/03	Janakiraman VAIDYANATHAN [signature]	1/6/03
2. Wayde Schmidt (RJ) [signature]	1/6/03	Kenneth PIETRZAK	
		LeRoy PUFFER	
Signatures	Date	Signatures	Date

INVENTION DISCLOSURE

Pratt & Whitney
A United Technologies Company

Title **Stereovision guided laser drilling system** Patent Project No. EH-10885

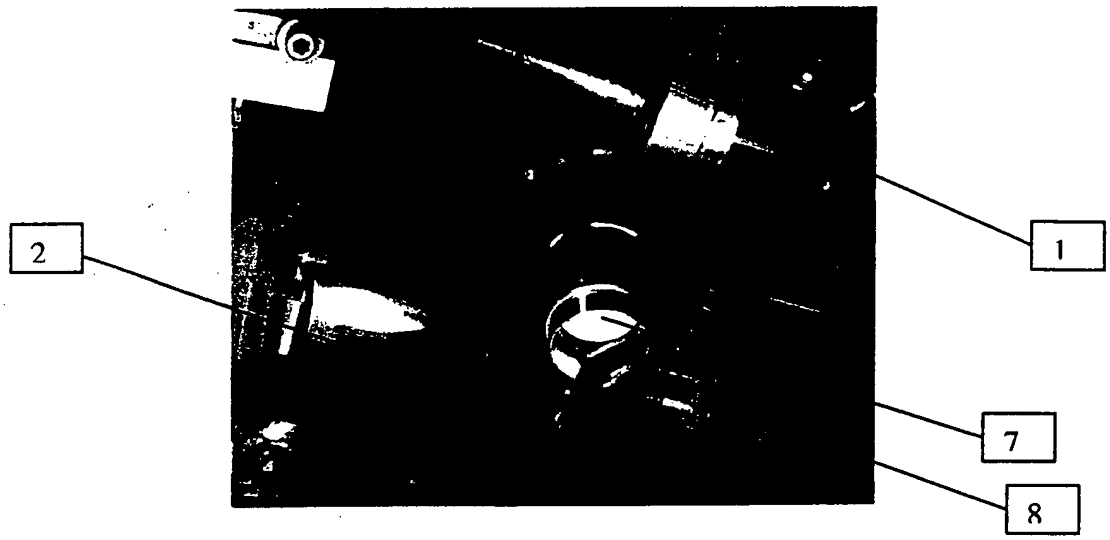

Fig 1 Stereovision system setup on the laser-drilling machine

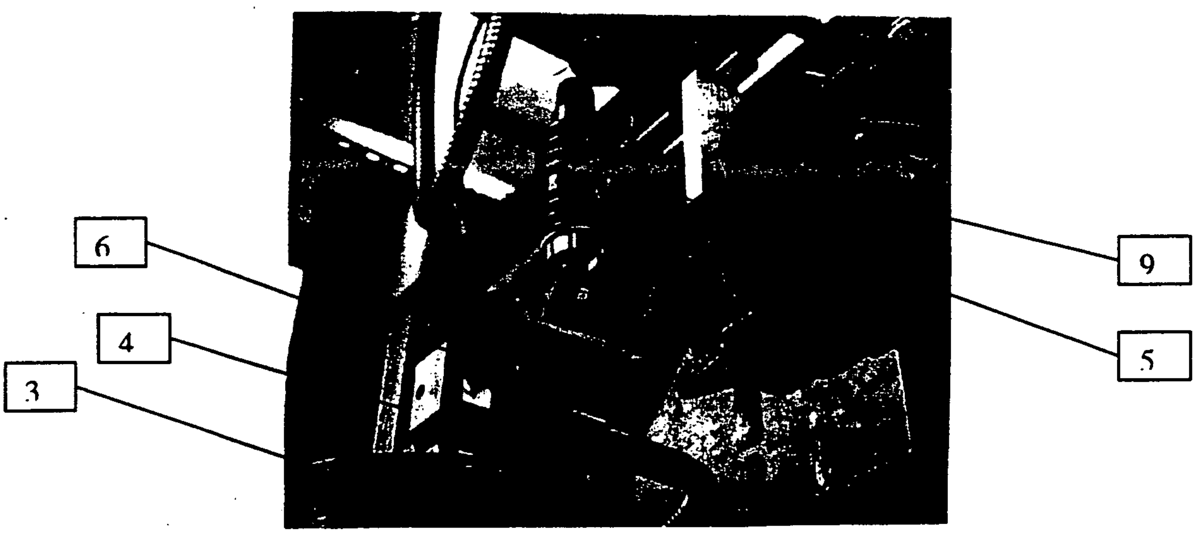

Fig 2 Vision system calibration setup

Explained to and understood by:		Inventor(s):	
1. Brice Cassenti N.	1/6/03	Janakiraman VAIDYANATHAN	1/6/03
2. Wayde Schmidt R.	1/6/03	Kenneth PIETRZAK	
		LeRoy PUFFER	
Signatures	Date	Signatures	Date

UTC FORM 5055 PG 1 REV. 6-02

INVENTION DISCLOSURE

Pratt & Whitney
A United Technologies Company

Title **Stereovision guided laser drilling system** Patent Project No. EH-10885

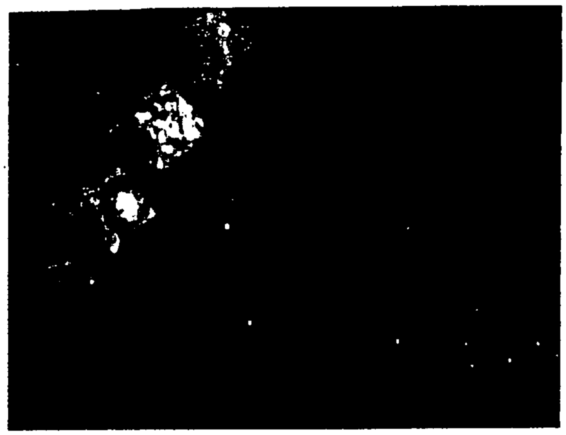

Fig 3 Set of 4 shaped cooling holes imaged before drilling

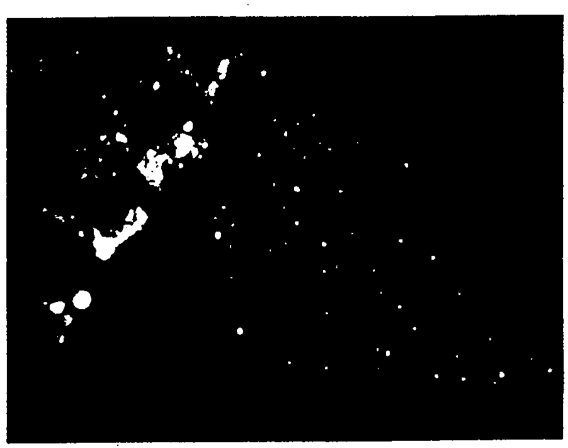

Fig 4 Same set of shaped cooling holes imaged after drilling

Explained to and understood by:		Inventor(s):	
1. Bruce Cassenti N. Bruce N. Cassenti	1/6/03	Janakiraman VAIDYANATHAN [illegible]	1/6/03
2. Wayde Schmidt R. [illegible]	1/6/03	Kenneth PIETRZAK	
		LeRoy PUFFER	
Signatures	Date	Signatures	Date